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# Cost-utility analysis of a web-based interactive patient education platform: evidence from a randomized clinical trial for end-stage renal disease patients

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## Abstract

**Objectives** Chronic kidney disease and its most severe complication, end-stage renal disease (ESRD), represents an estimated financial burden of €4.4 billion in 2021 in France. Therapeutic patient education (TPE) improves ESRD management and health outcomes. This study explored whether providing access to an interactive web-based TPE platform with community features was cost-effective.

**Methods** A within-trial cost-utility analysis was carried out over an 18 months horizon, using data from the PIC-R (*Plateforme Interactive Communautaire—dialyse et transplantation Rénale*) trial. ESRD or post-transplant patients were randomized 1:1:1 to a control group with no specific TPE program (Control), an intervention group with online TPE (e-TPE) and an intervention group with online TPE coupled with community features such as a patient forum and a chatroom with both patients and health care professionals (e-TPE + chat). The outcome measure was the cost per quality-adjusted life-year (QALY) and per year of full capability (YFC). Both intention-to-treat (ITT) and per protocol (PP) analyses were conducted, and missing data were handled using multiple imputation and selection models. Sensitivity analyses were performed.

**Results** Among the 815 patients assessed for eligibility across 12 French centres, a total of 549 patients were included in the economic analysis: 186 in the Control group, 189 in the e-TPE group and 174 in the e-TPE + chat group. The e-TPE group demonstrated cost savings and slightly higher QALYs compared to the control group, making e-TPE dominant. Conversely, the e-TPE + chat intervention resulted in higher costs without substantial effectiveness gains, making it not cost-effective.

**Conclusions** e-TPE was deemed cost-effective for ESRD patients, while e-TPE + chat was not. Web-based platforms improve ESRD management when targeted to likely users.

**Keywords** Cost-effectiveness analysis · Cost-utility analysis · End-stage renal disease · Patient therapeutic education · Randomized clinical trial · Web-based intervention.

**JEL classification** D61 Allocative Efficiency · Cost–Benefit Analysis

## Introduction

Chronic kidney disease (CKD) and its most severe complication, end-stage renal disease (ESRD), represents a significant global health challenge, with profound implications for both affected individuals and healthcare systems [1, 2]. In 2021 alone, ESRD affected 101,000 persons in France and its impact is not only measured in lives lost or deteriorations in patients' quality of life (QoL) but extends to the substantial

economic burden imposed by the treatments required, reaching €4.4 billion [3]. Thus, there is an urgent need to explore interventions that not only enhance patient outcomes but also contribute to the economic sustainability of healthcare systems [4]. Effective management of ESRD depends, in part, on patients' ability to understand their disease and identify complications or a worsening of their condition at an early stage. Along with treatment, therapeutic education plays a major role in providing patients with the knowledge and skills

Extended author information available on the last page of the article

essential for understanding and proactively managing their condition. In its economic assessment of end-stage chronic renal failure in 2014 [5], the French National Health Authority (HAS) emphasized the importance of therapeutic patient education (TPE) to reduce the probability of progression to more advanced stages of the disease. This educational component is crucial in empowering patients and enabling them to actively participate in their care, contributing, in so doing, to improved health outcomes [6, 7]. Patient associations increasingly provide forums to share experience and narratives among individuals facing similar health challenges and there is growing recognition of the benefits of such patient-to-patient interactions. Combining patient-to-patient with more traditional patient-to-professional interactions was the main purpose of the PIC-R (*Plateforme Interactive Communautaire—dialyse et transplantation Rénale*) platform, thereby enhancing existing TPE methods. Based on evidence showing their positive impact on patients' empowerment and prognoses, original web-based educational materials have been developed [8–11], allowing ESRD patients to receive information and updates about their disease, with direct interactions both with the care team and among themselves [12–15]. The PIC-R platform was expected to provide ESRD patients with an earlier detection of symptom deterioration through disease monitoring, and earlier intervention from the care team when needed, thereby reducing the need for emergency hospitalisations and ultimately slowing down disease progression.

In this study we conducted a cost-utility analysis of the online interactive TPE platform compared to usual care for patients with ESRD, based on PIC-R trial data. To the best of our knowledge, this was the first study aiming to assess both economic impacts and effectiveness of integrating an online interactive TPE platform with community features in the care pathway of patients with ESRD.

## Methods

### Population and design

The PIC-R trial, a prospective multicentre study, was conducted in 12 French nephrology centres. Patients were randomized 1:1:1 to a control group with no specific education program (Control) and two intervention arms (e-TPE and e-TPE+chat) which both provided access to a web-based e-Health platform offering patients therapeutic education, with exhaustive information and real-time updates about their condition. Only patients in the third arm (e-TPE+chat) benefited from additional community features' functionalities such as "likes," content sharing, forming connections, moderated forums, interest-based groups, and a chatroom with both patients and healthcare professionals. The platform's content, including TPE information,

news, advice, texts, emails, tests, and quizzes, was tailored and expanded by each participating centre to meet the unique needs of their own patients. Patients were aged at least 18 years, with a severe ESRD (postransplanted or undergoing dialysis treatment or neither). All patients had computer literacy and internet access and they provided written informed consents. The trial (ClinicalTrials.gov identifier: NCT03090828) was approved by the Ile de France ethics committee, and by the French national medicines agency (ANSM). Authorisation for the consolidated patient database was obtained from the French data protection committee (CNIL) and registered as DR 2017–272. Full details of the protocol have been published [16].

### Cost data

Costs, expressed in EUR 2022, were assessed from the perspective of the health care system, in accordance with HAS methods guidance. The time horizon covered a period of 18 months after randomization and a discount rate of 2.5% was applied in line with the French recommendations [17]. The study results were reported according to standard guidelines for economic evaluation [18].

Resource use items were recorded for each participant. The total costs per patient included the following resource items related to an ESRD condition: hospitalizations (inpatient, outpatient, home care hospitalization) including haemodialysis sessions, kidney transplant, specialist's (nephrologist) consultation, visits to the emergency department, transportation, and platform-related costs for patients enrolled in the two intervention arms. For hospitalizations and visits to the emergency department, resource use items were provided by local hospital discharge databases for each participant. Costs were assessed based on the diagnosis-related group (DRG) tariffs, or *groupe homogène de malades* (GHM) in France, using the average cost reported yearly in the French national costing study (*étude nationale de coûts – ENC 2022*) [19]. Additionally, patient-reported questionnaires provided information on other medical events and non-hospital care. This combined use of hospital records and patient-reported data enabled cross-validation, ensuring a thorough assessment of healthcare resource utilization. Costs of transportation were based on the French national health insurance accounts. An average amount reimbursed per transport to and from hospital of €<sub>2022</sub> 108.3 was applied. Platform-related costs for patients enrolled in the two intervention arms included costs related to health care professionals' (HCPs) training and activity. To estimate the former, information was collected through a questionnaire on the number of hours per month dedicated to activities related to the platform. Data from three representative centres (Pitié-Salpêtrière, Paris, Toulouse and Tours) were used to estimate the additional time spent by healthcare

professionals (physicians, nurses) on platform-related activities, which was then multiplied by unit costs (€<sub>2022</sub> 1.60 per minute for physicians and €<sub>2022</sub> 0.60 per minute for nurses). Licence costs that have been divided by the number of initially targeted patients ( $n=800$ ) were also included. Finally, costs related to additional community features' functionalities were allocated to the e-TPE+chat group, which was the only group to benefit from such functionality. Unit costs are presented in supplementary material 1.

One-way sensitivity analyses were conducted by varying platform-related costs parameters by plus or minus 20% and illustrated graphically in a tornado diagram using Treeplan SensIt<sup>®</sup>.

## Health-related outcomes

The primary health outcome of the cost-utility analysis was quality-adjusted life years (QALY) at 18 months. Participants completed the EQ-5D-5 L<sup>TM</sup> questionnaire at baseline, 9 months, and 18 months after randomization. This questionnaire assesses five dimensions of health-related quality of life (mobility, self-care, usual activities, pain/discomfort and anxiety/depression) on a 5-point scale. Overall health was scored using French specific EQ-5D weights [20]. QALYs were estimated for each participant at 18-months as the area under the curve of the EQ-5D-5 L<sup>TM</sup> index values.

In addition to the EQ-5D-5 L<sup>TM</sup>, the ICECAP-A (Investigating Choice Experiments Capability Measure for Adults) was administered at the same intervals (baseline, 9 months, and 18 months). The ICECAP-A is a capability-based measure that complements the EQ-5D by capturing broader aspects of well-being and capability, assessing five dimensions: stability, attachment, autonomy, achievement, and enjoyment. Each dimension is scored at four levels, from full capability to no capability. ICECAP-A utility scores, ranging from 0 (no capability) to 1 (full capability), were calculated using UK-specific tariffs derived from a best-worst scaling method [21]. These scores were used to estimate years of full capability (YFC) for each participant, calculated as the area under the curve of the ICECAP-A scores over the follow-up period [22].

Since the PIC-R is a biomedical study classified as negligible risk, no adverse events (AEs) were recorded in this study.

## Cost-utility analysis

The incremental cost-effectiveness ratios (ICERs) were calculated based on the mean cost differences between the intervention arms (e-TPE and e-TPE+chat) and the control arm, divided by the mean effectiveness differences (measured as both QALYs and YFC). This dual-outcome approach provides a more comprehensive assessment of

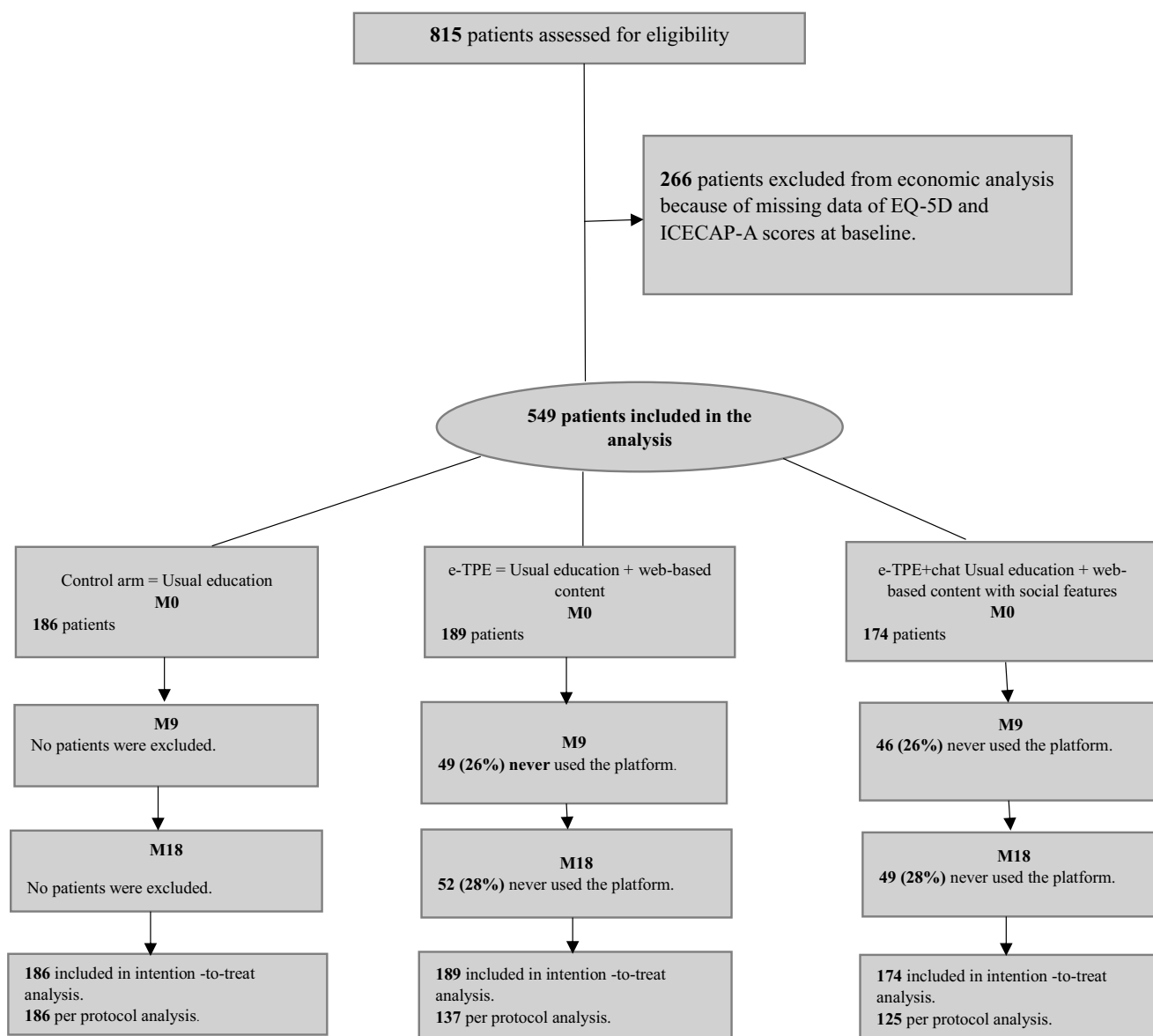
both health utility (QALYs) and overall quality of life (YFC) gained from each intervention. Although a reference value (i.e. a threshold representing the maximum acceptable ceiling ratio) is not specified in France, the European EuroVAQ project estimated the value of a QALY ranging from €1,811 to €54,612 [23, 24] for France, and if we refer to the publication of Pichon-Riviere et al., threshold based on per-capita health expenditures and life expectancy for France is US\$40,006 (2019 value) per QALY [25]. For this study, we used an updated threshold of €32,393 (2022 value), based on the estimate by Pichon-Rivière et al., adjusted for inflation using the Consumer Price Index (CPI) and subsequently expressed in euros at purchasing power parity. The uncertainty surrounding the ICERs was captured by a sensitivity analysis using non-parametric bootstrap methods as recommended by HAS. Simulated bootstrap samples (1000) were generated by independent draws with replacement from pairs constituted by the mean cost difference and the mean effectiveness difference between intervention arms, such that the correlation between cost and effectiveness was preserved. These 1000 pairs were represented by a scatter plot corresponding to an estimate of their joint distribution. Confidence regions for these pairs were represented by ellipses at the 50% and 95% levels. To further increase robustness, uncertainty surrounding ICER estimates was accounted for by calculating the probability to belong to each one of the quadrants of the cost-effectiveness plane, in addition to confidence ellipses. Results are also presented using cost-effectiveness acceptability curves (CEACs), which show the probability of each treatment having greatest net benefit, and rank probabilities, which show the probability each treatment has the greatest, second-greatest, third-greatest net benefit. Rank probabilities show a fuller picture than the CEAC of the uncertainty in the decision for multiple treatment comparisons [26]. The cost-effectiveness acceptability frontiers (CEAFs) were also generated to identify the treatment with the highest expected net benefit at each threshold.

## Handling of protocol deviations and missing data

Both intention-to-treat (ITT) and per protocol (PP) analyses, excluding patients who never used the platform, were carried out. To handle missing data [27], we initiated a thorough examination of the missing data mechanism, as suggested by R. Faria et al. [28]. We used a combination of descriptive statistics and linear logistic models to explore missing data. Descriptive statistics offered an initial view of the patterns of missing data. We subsequently incorporated indicators related to the missing data on both cost and EQ-5D-5 L, considering factors such as treatment allocation and a selection of baseline variables. The logistic models shed light on the relationship between the probability of data being missing and observed

information, enabling us to distinguish between missing completely at random (MCAR), missing at random (MAR), and missing not at random (MNAR) mechanisms [29]. Our results provided compelling evidence against the MCAR mechanism, indicating that the missing data in our dataset exhibited patterns. Therefore, multiple imputation using chained equations (MICE) [30] was employed to impute the remaining missing data under the assumption of missingness at random (see supplementary material 2). To account for the possibility of MNAR data, we conducted sensitivity analyses under various scenarios where the missing data is not missing randomly, ensuring that our findings remain robust across different potential mechanisms. A systematic strategy was used to address missing data by estimating two different

models. Model 1, MI using predictive mean matching (MI-PMM) coupled with a seemingly unrelated regression (SUR) model [31] was chosen to handle missing data under the assumption of MAR. MI using linear regression, and repeated measure mixed model were also explored, both models being well-established and widely recognized for their efficacy in scenarios where missing data can be considered random [32, 33]. Model 1 showed better performance in handling missing value imputation, (see supplementary material 2) which is in line with the conclusions of the literature [32]. Model 2 relied on a selection model under the assumption of an MNAR pattern [34]. This systematic exploration of missing data mechanisms contributes to the reliability and validity of our study results. All statistical analyses were



**Fig. 1** Consort diagram showing enrolment allocation baseline and follow-up

performed using STATA<sup>®</sup> software (version 17.0) (StataCorp LP; College Station, TX, USA) for Model 1 and R (version 3.0, R Foundation for Statistical Computing, Vienna, Austria) for Model 2.

## Results

### Patient characteristics

Among the 815 patients who were screened in the PIC-R trial from May 2018 to January 2021, 266 were excluded from the economic analysis for not having completed the initial EQ-5D and ICECAP-A questionnaires. Finally, 549 patients were included in the economic analysis: 186 (33.9%) in the control arm, 189 (34.4%) in the e-TPE arm and 174 (31.7%) in the e-TPE + chat arm (see Fig. 1). Protocol deviations, defined as lack of platform usage, were found for 101 patients who reported not having used the platform over the 18 months, with an equal distribution in the two intervention arms (52 in the e-TPE arm and 49 in the e-TPE + chat arm). The most frequently stated reason for not using the platform was that therapeutic information was readily available from other sources (71%). 448 patients were therefore included in the PP analysis.

Baseline characteristics were similar across the three arms (see Table 1).

### Costs

The total mean 18-months cost per patient is shown in Table 2 for both ITT and PP populations. In the ITT population, the mean (SD) total costs per patient were €13,344 (1,848), €12,657 (1,724) and €16,618 (2,379) for the control, e-TPE and e-TPE + chat arms, respectively. In the PP population, e-TPE + chat was also the costliest arm at €15,588 (2,728); The e-TPE arm recorded the lowest mean costs at €12,242 (2,021) as the costs of the platform (€472) were compensated by reduced medical costs (€11,769 (2,021) vs. 13,344 (1,848) for the control arm,  $p=0.009$ ). [Insert Table 2]. Regarding more specifically the costs of the platform, the overall estimated healthcare personnel cost per patient (HCPs training and involvement) for both the e-TPE and e-TPE + chat groups was €256.02 (Pitié-Salpêtrière, Paris: 1 physician hour for 7 patients led to a cost of €13.71 per patient per month (€246.86 total); Toulouse: 7 physician hours and 10 nurse hours for 60 patients led to a cost of €17.20 per patient per month (€309.60 total); Tours: 6 physician hours per month for 49 patients led to a cost of €11.76 per patient per month (€211.60 over 18 months)). Licence cost was estimated at €216.35 in the e-TPE arm and

**Table 1** Baseline characteristics

Characteristics	All (n=549)	Control (n=186)	e-TPE (n=189)	e-TPE+chat (n=174)
Age, mean (SD)	54 (13)	53 (13)	54 (14)	54 (13)
Sex, n (%)				
Women	204 (37%)	72 (39%)	66 (35%)	65 (37%)
Men	345 (63%)	113 (61%)	123 (65%)	109 (63%)
Married, n (%)	303 (55%)	100 (54%)	116 (61%)	87 (50%)
Higher Education, n (%)	355 (65%)	121(65%)	134 (71%)	100 (57%)
Occupation, n (%)				
Executive and liberal professions	98 (18%)	34 (18%)	41 (22%)	23 (13%)
Intermediate professions	22 (4%)	10 (5%)	9 (5%)	3 (2%)
Employee	148 (27%)	50 (27%)	44 (23%)	54 (31%)
Others	281 (51%)	92 (50%)	95 (50%)	94 (54%)
Smoker, n (%)	59 (11%)	25 (14%)	12 (6%)	22 (13%)
Causes, n (%)				
High blood pressure	69 (13%)	21 (11%)	26 (14%)	22 (13%)
Diabetes	58 (11%)	18 (10%)	13 (7%)	27 (16%)
Berger's disease or rheumatoid purpura	65 (12%)	21 (11%)	25 (13%)	19 (11%)
Autoimmune inflammatory disease	16 (3%)	7 (4%)	4 (2%)	5 (3%)
Polycystic kidney disease	120 (22%)	48 (26%)	48 (25%)	24 (14%)
Repeated pyelonephritis	8 (1%)	2 (1%)	3 (2%)	3 (2%)
Chronic abnormality or obstruction of the urinary tract	25 (5%)	6 (3%)	8 (4%)	11 (6%)
Others	114 (22%)	44 (24%)	32 (17%)	38 (22%)
Unknowns	74 (13%)	19 (10%)	30 (16%)	25 (14%)
Treatment, n (%)				
Post-transplant	401 (73%)	138 (74%)	137 (72%)	126 (72%)
Dialysis	68 (12%)	22 (12%)	22 (12%)	24 (14%)
Neither (no dialysis or transplantation)	80 (15%)	26 (14%)	30 (16%)	24 (14%)
EQ-5D Scores at M0 mean (SD)	0.90 (0.15)	0.90 (0.13)	0.90 (0.15)	0.89 (0.17)
ICECAP-A Scores at M0, mean (SD)	0.89 (0.11)	0.89 (0.11)	0.89 (0.11)	0.89 (0.1)

€228.68 in the e-TPE + chat arm. The difference comes from the training module, which only applies to eTPE + Chat. One-way sensitivity analyses of the costs of the platform showed that the most sensitive parameter was the number of patients using it (see supplementary material 3).

**Table 2** Mean costs per patient of usual e-TPE (control), e-TPE and e-TPE+chat strategies for ESRD treatment over 18 months (in €2022) after multiple imputation models

	Intention-to-treat Analysis			Per-Protocol Analysis		
	Control (n=186) Mean (SD)	e-TPE (n=189) Mean (SD)	e-TPE+chat (n=174) Mean (SD)	Control (n=186) Mean (SD)	e-TPE (n=137) Mean (SD)	e-TPE+chat (n=125) Mean (SD)
Costs of HCPs platform activities <sup>a</sup>	0	256	256	0	256	256
Costs of the platform licence and formation <sup>b</sup>	0	216	229	0	216	229
Costs of the platform (1)	0	472	485	0	472	485
Medical costs <sup>c</sup> (2)	13,344 (1,848)	12,185 (1,724)	16,133 (2,379)	13,344 (1,848)	11,769 (2,021)	15,104 (2,728)
Total costs (1)+(2)	<b>13,344</b> <b>(1,848)</b>	<b>12,657</b> <b>(1,724)</b>	<b>16,618 (2,379)</b>	<b>13,344</b> <b>(1,848)</b>	<b>12,242(2,021)</b>	<b>15,588</b> <b>(2,728)</b>

<sup>a</sup>HCPs health care professionals.

<sup>b</sup>The costs of the platform licence and formation differ between e-TPE and e-TPE+chat depending on whether or not the group includes additional community functions.

As we applied standard cost methodology, SDs are not applicable.

<sup>c</sup>Medical Costs included inpatient and outpatient care.

### Health-related outcomes

At 18 months, the mean (SD) QALYs in the ITT population were 1.36 (0.01) in the control arm, 1.38 (0.01) in the e-TPE arm, and 1.36 (0.02) in the e-TPE+chat arm. The corresponding values in the PP population were 1.36 (0.01), 1.39 (0.02), and 1.37 (0.02), respectively. Similar trends were observed for the YFC. At 18 months, the mean (SD) YFC scores in the ITT analysis were 1.35 (0.01) in the control group, 1.36 (0.01) in the e-TPE arm, and 1.36 (0.01) in the e-TPE+chat arm. The PP analysis yielded identical YFC scores for the control and e-TPE+chat groups, while the e-TPE group showed a slightly higher score of 1.36 (0.01).

Mortality rates remained low across all arms. At 18 months, 1 patient (0.5%) in the control arm had died, compared to 3 patients (1.6%) in the e-TPE group and 3 patients (1.7%) in the e-TPE+chat group under ITT analysis. In the PP analysis, mortality rates were 0.5% (1 patient) in the control arm, 2.2% (3 patients) in the e-TPE arm, and 2.4% (3 patients) in the e-TPE+chat arm (see supplementary material 4).

### Cost-utility analysis

Table 3 shows the results of the costs and QALYs after multiple imputation, along with the differences in YFCs. Multiple imputation models 1 and 2 include all 549 randomized patients, although 65% (357) had complete cost data at 18 months. The proportion of patients with complete costs, QALYs and YFCs data was similar in the control (68%), e-TPE (63%) and e-TPE+chat (63%) arms.

In the ITT population, patients in the e-TPE arm experienced lower costs compared to the control arm while

maintaining slightly higher QALYs. The mean (SD) cost differences per patient were -€747 (1,831) and -€267 (750) for multiple imputation models 1 and 2, respectively, with corresponding QALY differences of 0.02 (0.02) and 0.01 (0.01). Consequently, the e-TPE intervention was dominant in both models. The differences in YFCs were negligible at 0 (0.01) in model 1 and 0 (0) in model 2. Conversely, the e-TPE+chat intervention showed increased costs without substantial gains in effectiveness. Compared to the control, mean (SD) cost differences were €3,553 (2,400) in model 1 and €5,048 (1,988) in model 2, while QALY differences were 0 (0.02) and -0.01 (0.01), respectively. YFC differences followed a similar pattern, with no gains in model 1 and a slight reduction of -0.01 (0.01) in model 2. As a result, the e-TPE+chat intervention was dominated by the control arm in the ITT analysis, failing to provide improved health outcomes despite higher costs.

In the PP analysis, which excluded the 101 patients who reported never using the platform, the overall cost-effectiveness findings remained consistent with the ITT analysis. The e-TPE arm continued to be cost-saving, with mean (SD) cost differences of -€877 (2,090) and -€586 (856) in models 1 and 2, respectively, while maintaining QALY gains of 0.02 (0.02) and 0.01 (0.01). YFC differences remained stable at 0 (0.02) and 0 (0), reinforcing the cost-dominance of e-TPE in both models. For the e-TPE+chat intervention, costs were actually higher than the control arm, with mean (SD) cost differences of €2,353 (2,692) and €4,916 (2,621) in models 1 and 2, respectively. QALY differences remained minimal, at 0.01 (0.02) in model 1 and 0 (0.01) in model 2, and YFC differences were also small (0.01 (0.02) in model 1 and 0 (0) in model 2). As a result, the e-TPE+chat intervention was not cost-effective, with an ICER of €235,317

**Table 3** Results from non-parametric bootstrap for cost-utility analysis (in €2022)

		ITT (n=549)		PP (n=448)	
		Model 1	Model 2	Model 1	Model 2
		100 MI-PMM	Selection model	100 MI-PMM	Selection model
<b>Difference in cost</b>					
Mean	e-TPE vs. Control	-747 (1,831)	-267 (750)	-877 (2090)	-586 (856)
(SD)	e-TPE+chat vs. Control	3,553 (2,400)	5,048 (1,988)	2,353 (2,692)	4,916 (2,621)
<b>Difference in QALYs</b>					
Mean	e-TPE vs. Control	0.02 (0.02)	0.01 (0.01)	0.02 (0.02)	0.01 (0.01)
(SD)	e-TPE+chat vs. Control	0 (0.02)	-0.01 (0.01)	0.01 (0.02)	0 (0.01)
<b>Difference in YFCs</b>					
Mean	e-TPE vs. Control	0 (0.01)	0 (0)	0 (0.02)	0 (0)
(SD)	e-TPE+chat vs. Control	0 (0.01)	-0.01 (0.01)	0.01 (0.02)	0 (0)
<b>ICER</b>					
€/QALY	e-TPE vs. Control	e-TPE dominant	e-TPE dominant	e-TPE dominant	e-TPE dominant
	e-TPE+chat vs. Control	Control dominant	Control dominant	235,317	Control dominant
€/YFC	e-TPE vs. Control	e-TPE dominant	e-TPE dominant	e-TPE dominant	e-TPE dominant
	e-TPE+chat vs. Control	Control dominant	Control dominant	239,025	Control dominant

ITT intention-to-treat analysis.

PP protocol analysis (these models excluded patients who stated have never used the platform during the trial)

MI-PMM multiple imputation using predictive mean matching

e-TPE online patients' therapeutic education

e-TPE+chat online patients' therapeutic education enhanced with social features

YFC years of full capability

per QALY gained in model 1, while being dominated by the control in model 2. This suggests that the addition of social features did not improve cost-effectiveness.

The probabilities of the ICERs falling within each quadrant of the cost-effectiveness plane are detailed in Supplementary Material 5. In the ITT population (model 1), the

CEAC shows that at a willingness-to-pay (WTP) threshold of €32,393 per QALY, e-TPE has a 78% probability of yielding the highest net benefit, while control has a 22% probability, and e-TPE+chat has a 0% probability (Fig. 2a). In the PP analysis (model 1), the CEAC shows that at a threshold of €32,393 per QALY, e-TPE has an 79% probability of yielding the highest net benefit, followed by control at 21%, and e-TPE at 0%. Figure 2b presents the CEAF for the ITT population (model 1). Finally, Fig. 2c presents the rank probabilities of each treatment based on the mean net benefit and the variation in these rankings. The CEAC, CEAF, and rank probabilities for model 1 (PP population) and model 2 (ITT and PP populations) are provided in Supplementary Material 6. At a threshold of €32,393 per QALY, e-TPE ranks first, control second, and e-TPE+chat third in both ITT and per-protocol analysis.

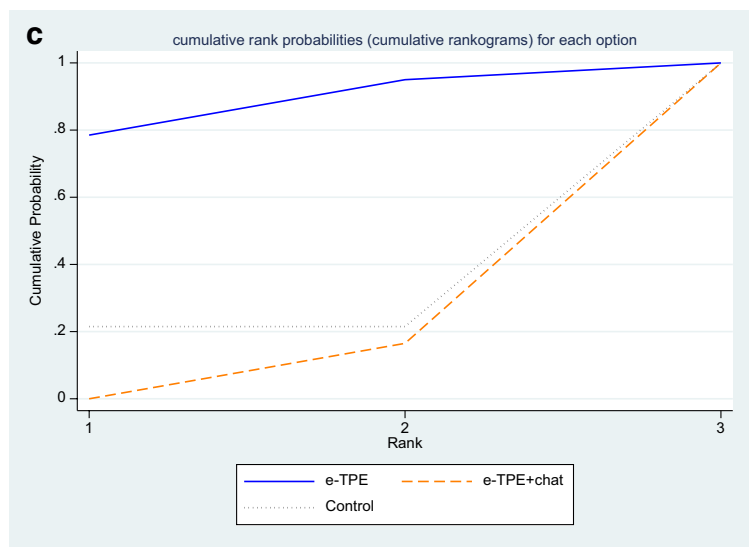
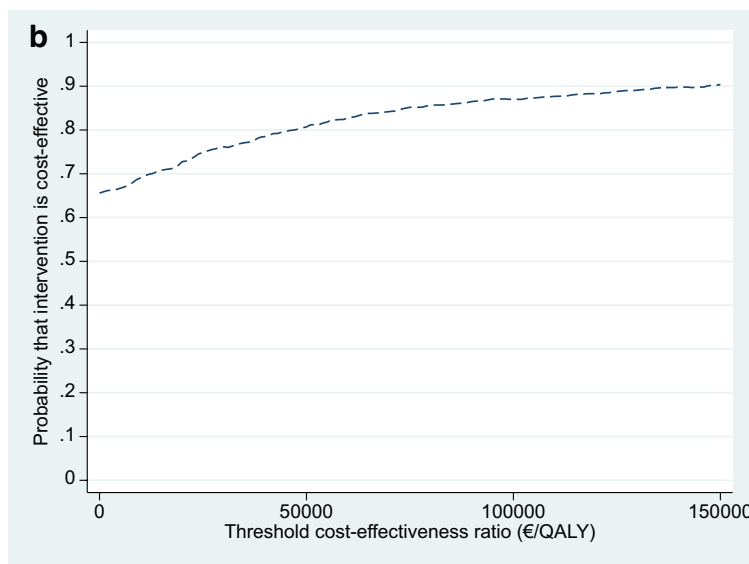
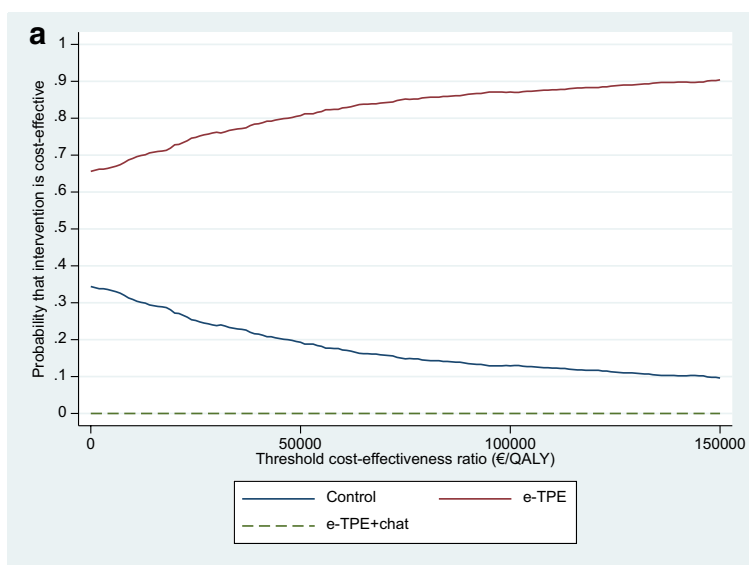
### Discussion

The present study provided insights into the cost-effectiveness of integrating a web-based interactive TPE platform into the care pathway for ESRD patients. Effective management of ESRD increasingly relies on the ability of patients to understand their disease and to identify complications or disease worsening at an early stage. Digital health innovations are transforming healthcare by fostering synergies between independent, hospital, and medico-social professionals, while also posing challenges in funding and evaluation [35]. As reimbursement frameworks for digital solutions evolve, their integration into healthcare systems requires careful assessment [36]. The HAS has issued a recent decision-support guide outlining key considerations for their integration into clinical practice, particularly in terms of safety, performance, and care coordination [37]. Our findings contribute to the growing body of evidence documenting the value of patient education in ESRD.

Our results first show that under ITT (multiple imputation models 1 and 2) and PP (both multiple imputation models 1 and 2) analyses, the e-TPE platform was cost-effective compared to standard care. Conversely, standard care remained more cost-effective than e-TPE+chat under ITT (multiple imputation models 1 and 2) and PP (model 2), with a particularly high incremental cost-effectiveness ratio (ICER) in PP (model 1), making it unlikely to be a cost-effective alternative. Given these findings, while the e-TPE platform offers good value for money, the inclusion of community features should be carefully considered in light of healthcare priorities and budget constraints.

Interestingly, costs were lower for both e-TPE and e-TPE+chat in the PP analysis (12,242 (2,021) and 15,588 (2,728)) compared to ITT analysis (12,657 (1,724) and

**Fig. 2** Cost-Effectiveness Acceptability Curves (CEAC) for Three Arms, Cost-Effectiveness Acceptability Frontiers (CEAF), and Rank Order of Treatments by Net Benefit for intention-to-treat population and model 1 2.a. Cost-effectiveness acceptability curves (CEAC)



16,618 (2,379), suggesting that active platform users may derive greater value from the intervention. Moreover, the e-TPE+chat arm demonstrated modest improvements in outcomes, reinforcing the potential benefits of interactive features when patients fully engage with them. However, patient engagement is crucial in the success of any web-based intervention. In this study, we found that 101 (18%) patients never used the platform, in line with similar studies of web-based platforms [38, 39]. To maximize effectiveness, the e-TPE+chat platform must better engage ESRD patients. Given the resource-intensive nature of community and social features, which require significant healthcare professional involvement, these should be selectively offered to patients most likely to benefit. This calls for further analyses of patients' characteristics to identify those most likely to benefit from community features.

This study has limitations. Despite patient randomization between the three arms at the beginning of the study, patients could not be blinded to the intervention. The second limitation is the length of the questionnaire which led to incomplete answers and subsequent exclusions. Even though the target number of patients was 1,200 (400 patients in each arm), only 549 patients were included in the analysis. Sample size, however, remained important compared to similar studies allowing patients' free choice of platform use [11, 39]. For instance, to study the effectiveness of a web-based educational intervention as a tool to reduce upper gastrointestinal tract endoscopy in un-investigated dyspepsia [11], included 119 patients while [39] involved 116 patients in an attempt to investigate the feasibility of a cross-platform smartphone application for Australian adults with chronic kidney disease.

The missing data rate in this study was 35%, and the non-engagement rate was 18%. While the study protocol anticipated a 15% dropout rate and a potential non-engagement rate of up to 30% [17], the actual non-engagement rate was lower than expected. Nonetheless, it underscores the ongoing challenge of patient engagement in web-based interventions. This highlights the need for targeted strategies to encourage participation among those most likely to benefit, ensuring optimal resource utilization. Future research should aim to identify factors influencing engagement to enhance the design and impact of digital health interventions. The main limitation remained the high level of missing cost data (26%), which can be attributed to several factors, including the decentralized nature of data collection across the 12 participating centres, variations in data recording practices, and the voluntary aspect of data submission, which tends to reduce the accuracy and completeness of healthcare records [27]. Therefore, missing data is an inherent weakness of local hospital data collection, requiring effective strategies for its management. Also, missing cost data in

French clinical trials may be explained to patient's freedom to choose between healthcare facilities, making it difficult to track costs in different settings. However, it is worth pointing out that missing cost data was distributed uniformly across the arms. The differences observed in costs in the two models are due to the different missing data mechanisms and the imputation model. Also, the systematic strategy used to manage missing data ensures that we conducted a cost-utility analysis while including all assumptions related to the missing data mechanism.

## Conclusion

This study assessed the added value of community features in a hospital-managed, web-based therapeutic patient education (e-TPE) platform, using a randomized clinical trial (RCT) over a period of 18 months. Our findings suggest that while the e-TPE platform is cost-effective compared to standard care, the addition of community features (e-TPE + chat) is less likely to be cost-effective. However, when actively used, the e-TPE+chat intervention showed slight improvements in patient outcomes, highlighting the importance of sustained engagement. Given the resource-intensive nature of community features, these should be selectively offered to patients most likely to benefit. Our results emphasize the need for tailored interventions and strategies to enhance patient engagement, ensuring the platform's optimal use and value for money within healthcare budget constraints.

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## References

- Wetmore, J.B., Collins, A.J.: Global challenges posed by the growth of end-stage renal disease. *Ren. Replace. Ther.* **2**, 15 (2016). <https://doi.org/10.1186/s41100-016-0021-7>
- Elshahat, S., Cockwell, P., Maxwell, A.P., Griffin, M., O'Brien, T., O'Neill, C.: The impact of chronic kidney disease on developed countries from a health economics perspective: A systematic scoping review. *PloS One*. **15**, e0230512 (2020). <https://doi.org/10.1371/journal.pone.0230512>
- Caisse Nationale d'Assurance Maladie: Améliorer la qualité du système de santé et maîtriser les dépenses Propositions de l'Assurance Maladie pour 2024. 4: (2024)
- Klarenbach, S.W., Tonelli, M., Chui, B., Manns, B.J.: Economic evaluation of Dialysis therapies. *Nat. Rev. Nephrol.* **10**, 644–652 (2014). <https://doi.org/10.1038/nrneph.2014.145>
- Évaluation médico-économique: des stratégies de prise en charge de l'insuffisance rénale chronique terminale en France. [https://www.has-sante.fr/jcms/c\\_1775180/fr/evaluation-medico-economique-des-strategies-de-prise-en-charge-de-l-insuffisance-renale-chronique-terminale-en-france](https://www.has-sante.fr/jcms/c_1775180/fr/evaluation-medico-economique-des-strategies-de-prise-en-charge-de-l-insuffisance-renale-chronique-terminale-en-france)
- Binik, Y.M., Devins, G.M., Barre, P.E., Guttman, R.D., Hollomby, D.J., Mandin, H., Paul, L.C., Hons, R.B., Burgess, E.D.: Live and learn: Patient education delays the need to initiate renal replacement therapy in end-stage renal disease. *J. Nerv. Ment Dis.* **181**, 371–376 (1993). <https://doi.org/10.1097/00005053-199306000-00006>
- Whaley-Connell, A., Shlipak, M.G., Inker, L.A., Kurella Tamura, M., Bombardieri, A.S., Saab, G., Szpunar, S.M., McFarlane, S.I., Li, S., Chen, S.-C., Norris, K., Bakris, G.L., McCullough, P.A.: Awareness of kidney disease and relationship to End-stage renal disease and mortality. *Am. J. Med.* **125**, 661–669 (2012). <https://doi.org/10.1016/j.amjmed.2011.11.026>
- Massey, E.K., Gregoor, P.J.H.S., Nette, R.W., van den Dorpel, M.A., van Kooij, A., Zietse, R., Zuidema, W.C., Timman, R., Busschbach, J.J., Weimar, W.: Early home-based group education to support informed decision-making among patients with end-stage renal disease: A multi-centre randomized controlled trial. *Nephrol. Dial. Transplant. Off. Publ. Eur. Dial. Transpl. Assoc. - Eur. Ren. Assoc.* **31**, 823–830 (2016). <https://doi.org/10.1093/ndt/gfv322>
- Xie, L.F., Itzkovitz, A., Roy-Fleming, A., Da Costa, D., Brazeau, A.-S.: Understanding Self-Guided Web-Based educational interventions for patients with chronic health conditions: Systematic review of intervention features and adherence. *J. Med. Internet Res.* **22**, e18355 (2020). <https://doi.org/10.2196/18355>
- Fredericks, S., Martorella, G., Catallo, C.: A systematic review of web-based educational interventions. *Clin. Nurs. Res.* **24**, 91–113 (2015). <https://doi.org/10.1177/1054773814522829>
- de Jong, J.J., Lantinga, M.A., Tan, A., Scheffer, R.C.H., Uil, J.J., de Reuver, P.R., Keszthelyi, D., Westert, G.P., Masclee, A.A.M., Drenth, J.P.H.: Web-Based educational intervention for patients with uninvestigated dyspepsia referred for upper Gastrointestinal tract endoscopy: A randomized clinical trial. *JAMA Intern. Med.* **181**, 825–833 (2021). <https://doi.org/10.1001/jamainternmed.2021.1408>
- Anderson, C.A.M., Wright, C.M., Ambeba, E.J.: A Web-Based Self-management sodium intervention in individuals with CKD. *Am. J. Kidney Dis. Off. J. Natl. Kidney Found.* **75**, 824–826 (2020). <https://doi.org/10.1053/j.ajkd.2019.12.009>
- Côté, J., Fortin, M.-C., Auger, P., Rouleau, G., Dubois, S., Boudreau, N., Vaillant, I., Gélinas-Lemay, É.: Web-Based tailored intervention to support optimal medication adherence among kidney transplant recipients: Pilot Parallel-Group randomized controlled trial. *JMIR Form. Res.* **2**, e14 (2018). <https://doi.org/10.2196/formative.9707>
- Vandenberg, A.E., Jaar, B.G., James, K.P., Lea, J., O'Donnell, C., Masud, T., Mutell, R., Plantinga, L.C.: Making sense of Dialysisconnect: A qualitative analysis of stakeholder viewpoints on a web-based information exchange platform to improve care transitions between Dialysis clinics and hospitals. *BMC Med. Inf. Decis. Mak.* **21**, 47 (2021). <https://doi.org/10.1186/s12911-021-01415-y>
- Maroney, K., Curtis, L.M., Opsasnick, L., Smith, K.D., Eifler, M.R., Moore, A., Wedd, J., Wolf, M.S., Patzer, R.E.: eHealth literacy and web-based patient portal usage among kidney and liver transplant recipients. *Clin. Transpl.* **35**, e14184 (2021). <https://doi.org/10.1111/ctr.14184>
- Pillebout, E., Durand-Zaleski, I., Farge, L., Perrier, L., de Chaisemartin, C., Dupont, J.C.K., Behaghel, L., Rochaix, L.: Paris school of economics and AP-HP hospinnomics, paris, france: Multicentre, randomised, economic evaluation of a web-based interactive education platform, simple or enhanced, for patients with end-stage renal disease: The PIC-R trial protocol. *BMJ Open.* **12**, e062613 (2022). <https://doi.org/10.1136/bmjopen-2022-062613>
- Haute Autorité de Santé: Choix méthodologiques pour l'évaluation économique à la HAS, [https://www.has-sante.fr/jcms/s/r\\_1499251/fr/choix-methodologiques-pour-l-evaluation-economique-a-la-has](https://www.has-sante.fr/jcms/s/r_1499251/fr/choix-methodologiques-pour-l-evaluation-economique-a-la-has)
- Misereau, D., Drummond, M., Augustovski, F., De Bekker-Grob, E., Briggs, A.H., Carswell, C., Caulley, L., Chaiyakunapruk, N., Greenberg, D., Loder, E., Mauskopf, J., Mullins, C.D., Petrou, S., Pwu, R.-F., Staniszewska, S.: Consolidated health economic evaluation reporting standards 2022 (CHEERS 2022) statement: Updated reporting guidance for health economic evaluations. *MDM Policy Pract.* **7**, 23814683211061097 (2022). <https://doi.org/10.1177/23814683211061097>
- ENC MCO | Stats ATIH: <https://www.scansante.fr/applications/enc-mco>
- Chevalier, J., de Pouvourville, G.: Valuing EQ-5D using time Trade-Off in France. *Eur. J. Health Econ.* **14**, 57–66 (2013). <https://doi.org/10.1007/s10198-011-0351-x>
- Flynn, T.N., Huynh, E., Peters, T.J., Al-Janabi, H., Clemens, S., Moody, A., Coast, J.: Scoring the Icecap-a capability instrument. Estimation of a UK general population tariff. *Health Econ.* **24**, 258–269 (2015). <https://doi.org/10.1002/hec.3014>
- Mitchell, P.M., Roberts, T.E., Barton, P.M., Coast, J.: Assessing sufficient capability: A new approach to economic evaluation. *Soc. Sci. Med.* **139**, 71–79 (2015). <https://doi.org/10.1016/j.socscimed.2015.06.037>

23. Donaldson, C., Baker, R., Pennington, M., Bell, S., Mason, H., Jones-Lee, M., Lancsar, E., Wildman, J., Robinson, A., Bacon, P., Olsen, J., Gyrd-Hansen, D., Kjaer, T., Beck, M., Nielsen, J.S., Persson, U., Bergman, A., Protière, C., Moatti, J., Kharroubi, S.: European value of a QALY (EuroVaQ) final report to european commission. *Health Econ* (2010). <https://pure.york.ac.uk/portal/en/publications/european-value-of-a-quality-adjusted-life-year>
24. Haute Autorité de Santé: Valeurs de références pour l' évaluation économique en santé: (2014)
25. Pichon-Riviere, A., Drummond, M., Palacios, A., Garcia-Marti, S., Augustovski, F.: Determining the efficiency path to universal health coverage: cost-effectiveness thresholds for 174 countries based on growth in life expectancy and health expenditures. *Lancet Glob Health*. **11**, e833–e842 (2023). [https://doi.org/10.1016/S2214-109X\(23\)00162-6](https://doi.org/10.1016/S2214-109X(23)00162-6)
26. Epstein, D.: Beyond the cost-effectiveness acceptability curve: The appropriateness of rank probabilities for presenting the results of economic evaluation in multiple technology appraisal. *Health Econ*. **28**, 801–807 (2019). <https://doi.org/10.1002/hec.3884>
27. Boudemaghe, T., Belhadj, I.: *Int. J. Epidemiol.* **46**, 392–392d (2017). <https://doi.org/10.1093/ije/dyw359> Data Resource Profile: The French National Uniform Hospital Discharge Data Set Database (PMSI)
28. Faria, R., Gomes, M., Epstein, D., White, I.R.: *Trials Pharmacoeconomics*. **32**, 1157–1170 (2014). <https://doi.org/10.1007/s40273-014-0193-3> A Guide to Handling Missing Data in Cost-Effectiveness Analysis Conducted Within Randomised Controlled
29. Little, R.J.A., Rubin, D.B.: *Statistical Analysis with Missing Data*. John Wiley & Sons (2014)
30. White, I.R., Royston, P., Wood, A.M.: Multiple imputation using chained equations: Issues and guidance for practice. *Stat. Med.* **30**, 377–399 (2011). <https://doi.org/10.1002/sim.4067>
31. MacNeil Vroomen, J., Eekhout, I., Dijkgraaf, M.G., van Hout, H., de Rooij, S.E., Heymans, M.W., Bosmans, J.E.: Multiple imputation strategies for zero-inflated cost data in economic evaluations: Which method works best? *Eur. J. Health Econ.* **17**, 939–950 (2016). <https://doi.org/10.1007/s10198-015-0734-5>
32. Diop, M., Epstein, D.: Comparing methods for handling missing cost and quality of life data in the early endovenous ablation in venous ulceration trial. *Cost Eff. Resour. Alloc.* **20**, 18 (2022). <https://doi.org/10.1186/s12962-022-00351-6>
33. Cox, E., Saramago, P., Kelly, J., Porta, N., Hall, E., Tan, W.S., Sculpher, M., Soares, M.: Effects of bladder cancer on UK health-care costs and patient Health-Related quality of life: Evidence from the BOXIT trial. *Clin. Genitourin. Cancer*. **18**, e418–e442 (2020). <https://doi.org/10.1016/j.clgc.2019.12.004>
34. Ma, Z., Chen, G.: Bayesian methods for dealing with missing data problems. *J. Korean Stat. Soc.* **47**, 297–313 (2018). <https://doi.org/10.1016/j.jkss.2018.03.002>
35. Gomes, M., Murray, E., Raftery, J.: Economic evaluation of digital health interventions: Methodological issues and recommendations for practice. *Pharmacoeconomics*. **40**, 367–378 (2022). <https://doi.org/10.1007/s40273-022-01130-0>
36. Charle-Maachi, C., Moreau-Gaudry, A., Sainati, D., Camus, D., Adenot, I., Barthelemy, C.-E., De Chalus, T., Debroucker, F., Denis, F., Gourio, C., Habran, E., Kamal, N., Le Douarin, Y.-M., Rosier, A., Schuck, S., Thébaut, J.-F., Trancart, A., Vercamer, V.: Les solutions numériques en santé, quelles valeurs apportées, quels mécanismes de financement et quelles évaluations? *Therapies* **77**, 117–132 (2022). <https://doi.org/10.1016/j.therap.2021.12.005>
37. Haute Autorité de Santé: Decision support guide for digital medical devices for professional use. Haute Aut Santé (2023). [https://www.has-sante.fr/jcms/p\\_3363066/en/digital-medical-devices-for-professional-use](https://www.has-sante.fr/jcms/p_3363066/en/digital-medical-devices-for-professional-use)
38. Hensel, J.M., Shaw, J., Ivers, N.M., Desveaux, L., Vigod, S.N., Cohen, A., Onabajo, N., Agarwal, P., Mukerji, G., Yang, R., Nguyen, M., Bouck, Z., Wong, I., Jeffs, L., Jamieson, T., Bhatia, R.S., Seeking Specialized Mental Health Care Services: Multi-center pragmatic randomized controlled trial. *J. Med. Internet Res.* **21**, e10838 (2019). <https://doi.org/10.2196/10838> A Web-Based Mental Health Platform for Individuals
39. Zwi, S., Isautier, J., Webster, A.C., Lambert, K., Shepherd, H.L., McCaffery, K.J., Sud, K., Saunders, J., O'Lone, E., Liu, N., Kim, J., Robbins, A., Muscat, D.M.: A feasibility study of a best practice health literacy app for Australian adults with chronic kidney disease. *PEC Innov.* **1**, 100047 (2022). <https://doi.org/10.1016/j.pecinn.2022.100047>

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